QUANTUM MEASUREMENTS, INFORMATION AND DUAL STATES REPRESENTATIONS

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22.09.2000

Abstract

The quantum measurement problem considered for the model of measuring system (MS) consist of measured state S (particle), detector D and information processing device (observer) O interacting with S,D. For 'external' observer O' MS evolution obeys to Schrodinger equation (SE) and O (self)description of MS reconstructed from it in Breuer ansatz. MS irreversible evolution (state collapse) for O can be obtained if the true quantum states manifold has the dual structure $L_T = \mathcal{H} \otimes \mathcal{L}_\mathcal{V}$ where $\mathcal{H}$ is Hilbert space and $\mathcal{L}_\mathcal{V}$ is the set with elements $V^O = |O_j\rangle\langle O_j|$ describing random 'pointer' outcomes O_j observed by O in the individual events. Possible experimental tests of this dual states structure described. The results interpretation in Quantum Information framework and Relational Quantum Mechanics discussed.

Talk given on 'Quantum communications and measurements' conference
Capri , July 2000, (Kluwer, N-H,2001)

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1 Introduction

Despite that Quantum Mechanics (QM) describe perfectly most of experimental effects in microscopic domain there still some difficult questions and 'dark spots' connected with its foundations and in particular Quantum Measurement Theory. Of them the problem of the state vector collapse or the objectification in general seems most remarkable and it's still unresolved despite the multitude of the proposed solutions (for the review see [1]). Eventually the measurements and collapse studies can help us to select the true QM interpretation out of many proposed. This paper analyses the information transfer to observer in the measurement and the collapse theory which is prompted by this considerations. We regard the microscopic dynamical model of measurements in which the evolution of the measuring system (MS) described from the first QM principles. In our approach MS in general includes the measured state (particle) S, detector D amplifying S signal and observer O which processes and stores the information. Under observer we mean information gaining and utilizing system (IGUS) of arbitrary structure [2]. It can be human brain or some automatic device processing the information , but in both cases practically it's the system with many internal degrees of freedom (DF) on which the large amount of information can be memorized. In general the computer information processing or perception by human brain is the physical objects evolution which on microscopic level supposedly obeys to QM laws [3].

Standard Copenhagen QM interpretation divide our physical world into microscopic objects which obeys to QM laws and macroscopic objects , including observers which supposedly are classical. This artificial partition was much criticized, first of all because it's not clear where to put this quantum/classical border. Moreover there are strong experimental evidences that at the dynamical level no such border exists and QM successfully describes large, complicated systems including biological ones.

The possible role of observer in quantum measurements was discussed for long time [5], but now it attracts the significant attention also due to the the progress of quantum information studies [4]. The class of microscopic measurement theories which attempts to describe observer quantum effects sometimes called Relational QM (for the review see [6]). In general Relational QM concedes that QM description is applicable both for microscopic states and macroscopic objects including observer O (he, Bob) which Dirack state vector $|O\rangle$ (or density matrix ρ for more realistic cases) can be defined relative to some other observer O' (she; Alice), which is also another quantum object. Of course this assumption it's not well founded and real O state can be much more complicated, but it's reasonable to start from that simple case. Consequently the evolution of any complex system C described by Schrodinger equation and for any C the superposition principle holds true at any time. MS measurement description by O formally must include evolution of O own internal DFs which participate in the interaction with S [3].

The role of observer in the measurement and its selfdescription called also selfmeasurement often regarded as the implication of the general algebraic and logical problems of selfreference [1]. Following this approach Breuer derived the general selfmeasurement restrictions for classical and quantum measurements [8]. This formalism don't resolve the measurement problem completely, but results in some important restrictions on its possible solution. From this analysis we propose modifica-

tion of standard QM Hilbert space formalism which aim is to describe measurement process consistently. Its main feature is the extension of QM states manifold permitting to account observer selfmeasurement features. Of course if some correction to quantum dynamics like in GRW model exist [11] then the state collapse can occur in macroscopic detectors. But until such effects would be found and the standard QM Hamiltonian can be regarded well established, we must inspect in detail observer properties in search of collapse.

In chap. 2 we describe our measurement model in detail. We argue that collapse description demands to change standard QM formalism and propose the particular variant of its modification. In chap. 3 we'll discuss *gedankenexperiments* which help to interpret our formalism and discuss its meaning. In chap. 4 physical and philosophical implications of this results and interpretation discussed.

Here it's necessary to make some technical comments on our model premises and review some terminology. In our model we'll suppose that MS always can be described completely (including Environment E if necessary) by some state vector $|MS\rangle$ relative to O' or by density matrix if it's in the mixed state. MS can be closed system , like atom in the box or open pure system surrounded by electromagnetic vacuum or E of other kind. We don't assume in our work any special dynamical properties of O internal states beyond standard QM.

In this paper the brain-computer analogy used without discussing its reliability and philosophical implications [4]. We'll ignore here quantum computer options having in mind only the standard dissipative computers. We must stress that throughout our paper the observer consciousness never referred directly. Rather in our model observer can be regarded as active reference frame (RF) which interacts with studied object. Thus S state description 'from the point of view' of the particular O described by the terms 'S in O RF' or simply 'for O'. The terms 'perceptions', 'impressions' used by us in a Wigner sense [5] of observer subjective description of experimental results and can be defined in strictly physical and Information theory terms (more discussion given in Conclusion).

2   Selfmeasurement and Weak Collapse

To perform the measurement one needs detector D and IGUS O each of them in practice have many internal DFs. In elementary measurement model the detector D and observer O only with one DF regarded corresponding to Von Neuman scheme. Account of many DFs for D and O doesn't change principally the results obtained below [9], but in addition it resolves the problem of 'preferred basis' arising for one DF detector model [10]. The example of dynamical model with many DFs gives Coleman-Hepp model described in [18].

Let's consider in this one DF ansatz O' description of the measurement performed by O of binary observable $\hat{Q}$ on S state :

$$\psi_s = a_1|s_1\rangle + a_2|s_2\rangle$$

, where $|s_{1,2}\rangle$ are Q eigenstates with values $q_{1,2}$. For the simplicity in the following we'll omit detector D in MS chain assuming that S directly interacts with O. It's possible for our simple model because if to neglect decoherence the only D effect

is the amplification of S signal to make it conceivable for O. Initial O state is $|O_0\rangle$ relative to O' RF and MS initial state is :

$$\Psi^0_{MS} = (a_1|s_1\rangle + a_2|s_2\rangle)|O_o\rangle \tag{1}$$

We assume that S-O measuring interaction starts at $t = t_0$ and finished at some finite t_1. From the linearity of Schrodinger equation for suitable interaction Hamiltonian $\hat{H}_I$ for some t_1 at $t > t_1$ the state of MS system relative to O' observer will be [1]

$$\Psi_{MS} = a_1|s_1^f\rangle|O_1\rangle + a_2|s_2^f\rangle|O_2\rangle \tag{2}$$

to which corresponds the density matrix $\hat{\rho}_{MS}$. Here $|O_{1,2}\rangle$ are O state vectors obtained after the measurement of particular Q eigenstate $|s_{1,2}\rangle$ and are the eigenstates of Q_O 'pointer' observable. In most cases one can take for the simplicity $|s_i^f\rangle = |s_i\rangle$ without influencing main results.

All this states including $|O_i\rangle$ belongs to Hilbert space $\mathcal{H}'$ defined in O' RF and Hilbert space $\mathcal{H}$ in O RF can be obtained performing unitary $\mathcal{H}'$ transformation $\hat{U}'$ to O c.m.s.(below state vectors with $n > 2$ components used with the same notations). $\hat{U}'$ can be neglected if only internal or RF independent discrete states regarded permitting to take $\mathcal{H} = \mathcal{H}'$. We suppose that for $t > t_1$ measurement definitely finished which simplifies all the calculations , but in fact that's fulfilled exactly only for the restricted class of models like Coleman-Hepp.

Thus QM predicts at time $t > t_1$ for external observer O' MS is in the pure state Ψ_{MS} of (2) which is superposition of two states. Yet we know from the experiment that macroscopic O observes some definite random Q_O value $q^O_{1,2}$ from which he concludes that S final state is $|s_1\rangle$ or $|s_2\rangle$. In standard QM with Reduction Postulate MS final state coincides with the statistical ensemble of such individual final states for O described by density matrix of mixed state ρ^s_m which presumably means the state collapse:

$$\rho^s_m = \sum_i |a_i|^2|s_i\rangle\langle s_i| \tag{3}$$

In our ansatz where where O regarded as quantum object interacting with S we can ascribe to MS the corresponding mixed state :

$$\rho_m = \sum_i |a_i|^2|s_i\rangle\langle s_i||O_i\rangle\langle O_i| \tag{4}$$

Normally the states in two RFs are connected by some unitary transformation , but no such transformation between (4) in O RF and (2) in O' RF is possible [1]. It's quite difficult to doubt both in correctness of O' description of MS evolution by Schrodinger equation and in collapse experimental observations. If observers regarded as quantum objects and accounted in measurement chain then this contradiction constitutes famous Wigner dilemma or 'Friend Paradox' for O, O' [5]. From O 'point of view' Ψ_{MS} describes superposition of two contradictory impressions : $Q = q_1$ or $Q = q_2$ percepted simultaneously. This paradox prompts to investigate possible QM formalism modifications and first one should investigate QM formalism of system description 'from inside'.

For realistic IGUS $|O_{1,2}\rangle$ can correspond to some excitations of O internal collective DFs like phonons, etc., which memorize this Q information, but we don't consider its particular physical mechanism here. It's necessary to formulate in our theory some minimal assumptions about relation between the observer states and his perception of the input quantum signal. We'll suppose that for any Q eigenstate $|s_i\rangle$ after S measurement finished at $t > t_1$ and O state is $|O_i\rangle$ observer O have the impression that the measurement event occurred and the value of outcome is q_i. If S state is the superposition ψ_s then we'll suppose that its measurement also result in appearance of some arbitrary O impression which properties will be discussed below. We stress that we don't suppose any special properties of biological systems. The simplest O toy-model of information memorization is hydrogen-like atom for which O_0 is ground state and O_i are the metastable levels excited by s_i, resulting into final S - O entangled state. This considerations have little importance for the following formalism rather they explain our philosophy of impressions-states relation.

Here we assumed that at $t > t_1$ measurement finished with probability 1, but for realistic measurement Hamiltonians it's only approximately true, because transition amplitudes have long tails. This assumption exactly fulfilled only for some simple models like Coleman-Hepp, but we'll apply it here to simplify our analysis. The more subtle question of exact time at which O percepts its own final state O_j isn't important at this stage. We'll assume that after S-O interaction S leaves O volume, which can be regarded as MS 'self-decoherence'. Thus final MS state quantum phase becomes unavailable for O. The practical decoherence mechanisms and their effects will be discussed in final chapter [9].

To discuss O selfdescription let's start with Breuer selfmeasurement theorem which is valid both for classical and quantum measurements [8]. Any measurement of studied system MS is the mapping of MS states set N_S on observer states set N_O. For the situations when observer O is the part of the studied system MS - measurement from inside, N_O is N_S subset and O state in this case is MS state projection on N_O called MS restricted state R_O. From N_S mapping properties the principal restrictions for O states were obtained in Breuer theorem. It proves that if for two arbitrary MS states S_{MS}, S'_{MS} their restricted states R_O, R'_O coincide then for O this MS states are indistinguishable. The origin of this effect is easy to understand : O has less number of DFs then MS and so can't describe completely MS state. For quantum measurements O restricted state can be the partial trace of complete MS state (2) :

$$R_O = Tr_s \hat{\rho}_{MS} = \sum |a_i|^2 |O_i\rangle\langle O_i| \tag{5}$$

R_O can be interpreted as O subjective state which describe his subjective perception. Note that for MS mixed state ρ_m of (4) the corresponding restricted state is the same $R_O^m = R_O$. This equality doesn't mean collapse of MS state Ψ_{MS}, because it holds for statistics of quantum ensembles, but collapse appearance also must be tested specially for individual events states. Such restricted R_O form assumes that O can percept only his internal excitations independently of quantum correlations with S state. This assumption can be wrong for quantum systems due to well known quantum entanglement and in fact its study shows that from equality of restricted states doesn't follows the transition of pure system state to mixed one.

Exploring individual events it's important to note that for mixed incoming state

S MS individual state in event n differs from statistical state (4) and is equal to :

$$\rho_n^m = |O_l\rangle\langle O_l||s_l\rangle\langle s_l|$$

with arbitrary, random $l(n)$ which in standard QM objectively exists in event n, but can be initially unknown for O [8]. Its restricted state is $R_O^n = |O_l\rangle\langle O_l|$ and so differs always from R_O of (5). Due to it main condition of Breuer Theorem violated and so this theorem isn't applicable for this situation and O can differentiate pure/mixed states 'from inside'. It means that the restricted states ansatz doesn't prove the collapse appearance in standard QM formalism even with inclusion of observer quantum effects in the measurement models. The analogous conclusions follows from the critical analysis of Witnessing interpretation [7, 13]. As we noticed already statistical restricted states for mixed and pure states R_O^m, R_O coincide, but it doesn't mean as Breuer claims that in ensemble observer O can't differ pure and mixed state. The reason is that O can analyse ensemble properties not only statistically, but on event by event basis regarding N-events restricted state which is tensor product of N R_O^n states which all components differ from R_O. Really it would be strange otherwise if in each event pure and meixed state differs, but ensemble of events don't reveal any difference.

Additional arguments in favor of this conclusion reveals MS interference term observable :

$$B = |O_1\rangle\langle O_2||s_1\rangle\langle s_2| + j.c. \tag{6}$$

being measured by O' gives $\bar{B} = 0$ for mixed MS state (4) , but in general $\bar{B} \neq 0$ for pure MS state (2). It evidences that even for statistical ensemble the observed by O' effects differentiate pure and mixed MS states. Note that B value principally can't be measured by O directly, because O performs Q measurement and $[Q, B] \neq 0$ [9].

Breuer analysis is quite useful, because in fact it prompts the minimal modification of MS states set N_S which can describe MS state collapse. Here we'll demand that QM modification in our theory satisfy to two main operational conditions :
i) if S (or any other system) don't interact with O then for O this system evolves according to Schrodinger equation dynamics (SD) (for example GRW theory brokes this condition [11]).
ii) If S interacts with O (measurement) SD can be violated for O so that he percepts random events, but in the same time as O' doesn't interact with S or O i) condition settles that in O' RF MS must be described by SD. It means that in such formalism MS final states relative to O and O' are nonequivalent [1]. We'll call this phenomena the weak (subjective) collapse which obviously has looser conditions then standard QM Reduction Postulate. We attempt to satisfy to both this conditions performing minimal modification of QM states set - which in standard QM is Hilbert space. This modified set must incorporate simultaneously both linear states evolution and random events observed by O, but Schrodinger dynamics must be conserved copiously if interaction with observer absent. It's worth to remind that Hilbert space is in fact empirical construction which choice advocated by fitting most of QM data, and so QM states set modification isn't unthinkable in principle. Such attempts were published already and most famous is Namiki-Pascazio many Hilbert spaces formalism [21]. In standard QM formalism all its states manifold representations are unitarily equivalent, but observers interactions and evolution aren't considered in

it. It will be shown that our new formalism in some sense is analog of the nonequivalent representations of states manifold. Analogous superselection systems are well studied for nonperturbative Field theory (QFT) with infinite DF number [22]. This approach was applied for measurement problem, but it's not clear its applicability for finite systems [23, 9].

Remind that experimentalist never observes state vector directly, but his data consists of individual random events like detector counts and the state vector reconstructed from observed random events statistics. Following this notion we'll suppose that the perception by O of individual events to large extent is independent of system state vector $\Psi_{MS}(t)$. This prompts to regard QM dual representations, in which state vector and observer information presented simultaneously by independent entities. To illustrate the formalism features and introduce its terminology let's describe as example how such formalism describes O measurement of some parameter q with probabilistic distribution $P^c(q)$ which describe the classical statistical ensemble. For such $P^c(q)$ distribution (or P_l^c array for discrete q) when O measures q he acquires instantly information about q value and initial O_0 state changes to some O_j correlated with measured q_j. Formally at this moment $P^c(q)$ collapses to delta-function, but in classical case this effect reflects only O information change. For q discrete the observer information $O(n) = O_i$ in given event n presented by 1-dimensional matrix $V_l^O = \delta_{li}O_i$. For complete system description we can use formally the dual event-state as $\Phi_{clas} = P^c \otimes V^O$. It incorporates statistical state of ensemble P^c and O information in the individual event n. and such dual form acquires nontrivial meaning for our modified QM states set. Note that V^O by itself is unavailable to other O', which can get this information only via signalling between this two observers, i.e. their interaction whcih in principle must be accounted.

To explain the main idea for the beginning we regard this new formalism applied to our MS system evolution. O and O' Hilbert spaces $\mathcal{H}, \mathcal{H}'$ will be our initial basis, and QM density matrices manifold $L_q = (\rho \geq 0, Tr\rho = 1)$ constructed of $\mathcal{H}$ state vectors will be used. Analogously to classical example ρ is one component of our dual state $\Phi(n) = \rho \otimes V^O(n)$ and V^O describes the outcome of individual event. Alike in standard QM ρ obeys always including measurement process to Schrodinger-Liouville equation for arbitrary MS Hamiltonian $\hat{H}_c$:

$$\dot{\rho} = [\rho, \hat{H}_c] \tag{7}$$

which for pure states is equivalent to Schrodinger equation. Initial $\rho(t_0)$ states defined also by standard QM rules. Inside L_q we extract O restricted states analogously to (5) $R_O = Tr_s\rho$ and calculate in O basis weights matrix

$$P_j(t) = Tr(\hat{P}_j^O R_O) = Tr(\hat{P}_j^O \rho(t)) \tag{8}$$

where $\hat{P}_j^O$ is O_j projection operator. For (2) and $t > t_1$ it gives $P_j = |a_j|^2$ equal to standard QM reduction probabilities. We suppose that P_j is the probabilistic distribution which describes individual events outcomes O_j percepted by O after S-O interaction. In distinction from standard QM this subjective O information in the individual event is only statistically correlated with final $\rho(t)$ at $t > t_1$ and described by random vector $V^O = |O_j\rangle\langle O_j|$ in the individual event corresponding to observation of random Q value q_j. Despite that O percepts some random outcome O_j

due to regarded V^0 independence $\rho(t)$ evolves all the time according to Schrodinger-Liouville equation and doesn't suffers the abrupt state collapse to ψ_j. Thus our dual state or event-state, which due to $j(n)$ randomness differs for each individual event n for O is doublet of dynamical and information component :

$$|\Phi_n \gg = |\phi_D, \phi_I \gg = |\rho, |O_j\rangle\langle O_j| \gg \tag{9}$$

V^O has the special 'information' dynamics regarded below and only statistically correlated with ϕ_D. Before measurement starts O state is $|O_0\rangle$ and the dual state is $\Phi = |\rho_{MS}(t_0), V_0^O \gg$ where $V_0^O = |O_0\rangle\langle O_0|$, so that initial O information described both by V_0^O and $\rho_{MS}(t_0) = |\Psi_{MS}^0\rangle\langle\Psi_{MS}^0|$ The time of $V_0^O \rightarrow V_j^O$ transition for O is between t_0 and t_1 and can't be defined in the current formalism with larger accuracy, but it doesn't seems very imortant at this stage. O' doesn't interact with MS and due to it MS final state for her is Ψ_{MS} of (2) as regarded in detail below.

Probabilities P_j coincides with corresponding standard QM probabilities $P_j^Q = Tr(\hat{P}_{Sj}|\psi_s\rangle\langle\psi_s|)$ of particular outcome q_j. [1]. If we restricts only to statistical ensemble description and aren't interested in particular event outcome then statistical dual state can be defined :

$$|\Theta^s) = \rho \bigotimes \{V^P\}$$

where $\{V^P\}$ is $V_j^P = P_j$ vector, describing probabilistic distribution of$V^O = |O_j\rangle\langle O_j|$ outcomes in L_V subset.

Complete manifold in O RF for this event-states is $N_T = L_q \otimes L_V$ i.e direct product of dynamical and subjective components. L_V is the linear space of diagonal positive matrices or vectors V^O with $trV^O = 1$ and consequently $|\Phi| = 1$ for all such states. If we restrict our consideration only to pure states as we do below then N_T is equivalent to $\mathcal{H} \otimes L_V$ and the state vector can be used as the dynamical component ϕ_D. O_j entangled with s_j and in place of V^O equivalent to it MS subjective dual state component $V^{MS} = |O_j\rangle\langle O_j||s_j\rangle\langle s_j|$ can be used.

Naturally in this formalism O' has her own subjective space L_V' and in her RF the events states manifold is $N_T' = \mathcal{H}' \otimes L_V'$ for pure states. From the described features it's clear that subspace L_V is principally unobservable for O' (and vice versa for L_V', O), because in this formalism only the measurement of ϕ_D component described by eq. (7) permitted for O'. But V^O, V'^O can be correlated statistically via special measurement by O' of dynamical component ϕ_D. For this purpose O' can measure Q_O on O getting the information on V^O content, which mechanism we'll discuss in next chapter. Formally O' also can ascribe to MS V^O internal coordinate but j value is uncertain for her in Ψ_{MS} final state and so it has little sense. It means that O' is sure that O knows q_j value, but O' don't know this value. In general if in the Universe altogether N observers exists then the complete states manifold described in O RF is $L_T = \mathcal{H} \otimes L_V \otimes L_V'...\otimes L_V^N$ of which only first two subsets are observed by O directly and all others available only indirectly via $\mathcal{H}$ substates.

Standard QM reduction postulate also describes how the state vector correlates with the changes of observer information in the measurement. The main difference is that in place of abrupt and irreversible state vector ψ_s reduction to some random state vector ψ_j in standard QM in our formalism the dynamical component Ψ_{MS} of MS event-state evolves linearly and reversibly in accordance with (7). It's only subjective component which changes abruptly and probabilistically describing

O subjective information about S. We must stress that subjective or informational V^O component of Φ_n isn't the new degree of freedom, but O internal coordinate Q_O which (self)description relative to O doesn't covered by MS Hilbert space $\mathcal{H}$ vector Ψ only. Q information for O' which don't interact with S completely described by Ψ_{MS}, which means uncertainty $q_{min} < Q < q_{max}$. V^O substate contains additional information $Q = q_j$ available for O only. In such theory O can percept only (random) part of the full state vector Ψ_{MS} which continue to exist. Schrodinger dynamics and collapse coexist, by the price that S signal perception by O occurs via this new stochastic mechanism. Despite we use term 'perception' in our model it doesn't referred to human brain specifically. We believe that as O can be regarded any system which can produce the stable entanglement of its internal state and measured state S. As we mentioned already it can be even hydrogen-like atom in the simplest model for which O_i can be different atomic levels. Perception corresponds to V^O component presence which means that in such formalism O states completely described only by O 'from inside' and not by any other O'.

Now let's describe dual formalism for pure states in details. If S don't interact with O (no measurement) then V^O is time invariant and one obtains standard QM evolution for event-state dynamical component $\phi_D = \Psi$ - state vector. Thus our dual states are important only for measurement-like processes with direct O interactions, but in such case it's always the analog of regarded MS system. Its dual state is $|\Phi \gg = |\Psi_{MS}, V^O \gg$ and its evolution defined by initial $\Psi_{MS}(t_0)$ and the formal system of equations :

$$
\begin{aligned}
i\dot{\Psi}_{MS} &= \hat{H}_c \Psi_{MS} \\
P_j &= Tr(\hat{P}_j^O |\Psi_{MS}\rangle\langle\Psi_{MS}|) \\
l &= Rnd(P) \\
V^O &= |O_l\rangle\langle O_l|
\end{aligned}
\tag{10}
$$

where $Rnd(P)$ is the random numbers generator for P distribution producing random index $l(n)$ in the individual event n. [25]. The statistical dual state $|\Theta^s)$ evolution defined by first two equations. The first equation of (10) is Schrodinger equation which becomes here the analog of master equation for probabilities P_j describing V^O probabilistic distribution.

Due to independence of MS dynamical state component ϕ_D of internal parameter j of V^O this O-S Φ evolution is reversible. Thus in dual formalism no experiment performed by O' on MS wouldn't contradict to standard SD. If O perform selfmeasurement experiment on MS the situation is more subtle and will be discussed in the next chapter. Note that in this formalism parameter j don't existed before S-O interaction starts.

Above L_V corresponds to the simplest measurement and in general it will can have much more complicated form corresponding to O information channels and O structure. As we noticed their parameters must correlate to the complex probabilities of standard QM [1]. For example 2-dimensional values correlation measurement by O has the distribution :

$$
P_{ij} = Tr(\rho \hat{P}_{1i}^O \hat{P}_{2j}^O)
\tag{11}
$$

where $\hat{P}^O$ are projectors on O memory states $|O_i^1\rangle, |O_j^2\rangle$. Corresponding set structure is $L_V = V^{O1} \otimes V^{O2}$.

Extension of dual formalism on completely mixed states is obvious and here it presented only for the states interested for measurements of the kind (4). For them from eq. (8) naturally follows $P_j = |a_j|^2$ which gives V^O distribution. In dual formalism the restricted MS state $R^V = |O_l\rangle\langle O_l|$ where $l(n_1)$ in the individual event n_1 defined by (10). It differs from restricted state R_O in standard QM given by (5), but coincide with restriction of mixed state ρ_n^m in the individual event n if $l(n_1) = l(n)$. Thus Breuer theorem condition fulfilled in dual formalism as expected.

Obviously in this formalism $\bar{Q}$ coincide both for O and O'. If one interested only to calculate $\bar{Q}$ after S measurement by O or any other expectation values ignoring event structure it's possible to drop V^O component and to make standard QM calculations for ρ. If one regards the statistical results for quantum ensembles then statistics in L_V subspace corresponds to $|a_j|^2$ the probabilities of particular O observation. Note that their meaning differs from O' representation where they can't be regarded as probabilities but only like some weights. Because O observes random Q values then if in addition to demand that $\bar{Q}$ coincide both for O and O' then one obtains that Q distribution for O described by $|a_j|^2$. Thus dual formalism gives naturally the values of outcome probabilities $|a_i|^2$ which is quite difficult to obtain in some theories explaining state collapse like Many Worlds Interpretations (MWI) [1].

To exclude spontaneous V^O jumps without effective interactions with external world we introduce additional O identity condition : if S and O don't interact then the same random parameter j of V^O conserved. We extend it to more general condition : if different Ψ_{MS} O_j branches don't intersects i.e. $\langle O_i|\hat{H}|O_j\rangle = 0, i \neq j$ then V_j^O conserved. As we noted it means that O observes constantly only $|s_j\rangle$ branch of S state. Note that this condition doesn't influence on MS dynamics defined by ρ, but only on dynamics of O information V^O. Such condition is natural if P_i can be regarded as transition probabilities $V_0^O \rightarrow V_i^O$ resulting from action of $\hat{H}_I$. Really P_i can be rewrited as :

$$P_i = |\langle \Psi_i|U(t_1 - t_0)|\Psi_{MS}^0\rangle|^2$$

where $\hat{U}$ unitary trasformation in time. In this case if S-O stops to interact $\hat{H}_I(t) = 0$ then all $P_{ij} = 0$ and it's compatible with absense of such jumps.

Note that in general the theory can be formulated even without this condition, because O or any other observer can't indicate that such jumps occurs. The reason is that in our model O memory described by V^O and if the jump $j \rightarrow i$ occurs no memory about previous state can be conserved. For more complicated memory structure such jumps should occurs simulteneosly in many cells with entangled states. Thus this condition simplifies the theory and make it more reasonable but in general isn't necessary.

In our formalism parameter j of V^O defined at random with probabilities $P_j = |a_j|^2$ in S measurement. In general to calculate Φ evolution for arbitrary complex system MS equations (10) for MS Hamiltonian can be used and $P_j(t)$ found. Then from $P_j(t)$ at the time when S-O interaction finished we find random V^O which constitute stochastic component of our quantum dynamics. So if we have several S-O rescatterings each time after the interaction finished we get new V^O state component

which effect in details will be discussed below. Note that practically we must be interested only in final O state, because in this model O has no memory about intermediate states.

We noticed already that in standard QM formalism in MS state (4) Q, Q_O aren't objectively existing for O' which is serious argument against Witnessing interpretation [13]. That's true also in our ansatz, but in its framework in the same time Q and Q_O have objective values Q_j, Q_{Oj} in O RF. Note that the physical meaning of Hilbert space $\mathcal{H}$ in our formalism differs from standard QM, because in it all its Hermitian operators are O observables, but the operator B of (7) isn't observable for O. Due to it we can speculate that B observable for O transformed into stochastic parameter V_j^O, which seems natural generalization of standard QM on observer evolution. Really B describes observer O internal state parameters, and so such transformation don't contradicts to standard QM applicability for any external objects. Realistic O has many internal DFs practically unobservable for him and previously we assumed that they are responsible for randomness in the quantum measurement [9].

3   Collapse and Quantum Memory Eraser

To discuss measurement dynamics in our formalism for more subtle situations let's consider several *gedankenexperiments* for different selfmeasurement effects, the first one means 'Undoing' the measurement. Such experiment was discussed by Vaidman [16] and Deutsch [17] for many worlds interpretation (MWI), but we'll regard its slightly different version. Its first stage coincides with regarded S state (1) measurement by O resulting in the final state (2). This S measurement can be undone or reversed with the help of auxiliary devices - mirrors, etc., which come into action at $t > t_1$ and reflects S back in O direction and make them reinteract. It permit for the final state Ψ_{MS} obtained at time t_1 at the later time t_2 to be transformed backward to MS initial state Ψ_{MS}^0. In any realistic layout to restore state (1) is practically impossible but to get the arbitrary S-O factorized state by means of such reversing is more simple problem and that's enough for such tests. Despite that under realistic conditions the decoherence processes make this reversing immensely difficult it doesn't contradict to any physical laws.

If we consider this experiment in standard QM from O point of view we come to some nontrivial conclusions. When memorization finished at t_1 in each event MS collapsed to some arbitrary state $|s_i\rangle|O_i\rangle$. Then at t_2 O undergoes the external reversing influence, in particular it can be the second collision with S during reversing experiment and its state changes again and such rescattering leads to a new state correlated with $|s_i\rangle$:

$$|s_i\rangle|O_i\rangle \rightarrow |s_i'\rangle|O_0\rangle$$

It means that O memory erased and he forgets Q value q_i, but if he measure S state again he would restore the same q_i value. Its statistical state is

$$\rho_m' = |O_0\rangle\langle O_0| \sum |a_i|^2 |s_i'\rangle\langle s_i'|$$

But this S final state differs from MS state (1) predicted from MS linear evolution observed by O' and in principle this difference can be tested on S state without O

measurement. In our doublet formalism it's necessary also to describe subjective event-state component V^O which after measurement becomes some random V_j^O. But after reversing independently of j it returns to initial value V_0^O , according to evolution ansatz (10) described in previous chapter. If such description of this experiment is correct, as we can believe because its results coincides with Schrodinger evolution in O' it follows that after q_i value erased from O memory it lost unrestorably also for any other possible observer. If after that O would measure Q again obtained by O new value q_j will have no correlation with q_i, but O can't make this comparison in principle.

Of course one should remember that existing for finite time intermediate O states are in fact virtual states and differ from really stable states used here, but for macroscopic time intervals this difference becomes very small and probably can be neglected.

The analogy of 'undoing' with quantum eraser experiment is straightforward : there the photons polarization carry the information which can be erased and so change the system state [14]. The analogous experiment with information memorization by some massive objects like molecules will be important test of collapse models.

Note that observer O' can perform on O and S also the direct measurement of interference terms for (2) without reversing MS state. Such experiment regarded for Coleman-Hepp model in [9] doesn't introduces any new features in comparison with 'Undoing' and so we don't discuss it here.

The second experiment is the comparison of two independent measurements. In first one at the initial stage O measures Q value of S at t_1 which results in MS state (2) for O', but after it Q is measured again by observer O' at $t_2 > t_1$. The interaction of O' with MS results in entangled state of S,O and O' and so both observers acquire some information about S state. This state vector in our formalism is:

$$\Psi'_{MS} = |a_1|s_1\rangle|O_1\rangle|O'_1\rangle + a_2|s_2\rangle|O_2\rangle|O'_2\rangle \tag{12}$$

Such experiments discussed frequently due to its relation to EPR-Bohm correlations and here we regard only its time evolution aspects. Our question is : at what time Q value becomes certain and S state collapse occurs for O' ? In our formalism at $t_1 < t < t_2$ observer O already acquired the information that Q value is some q_i, reflected by $\phi_I = |O_i\rangle\langle O_i|$. In the same time Q value stays uncertain for O', because relative to her MS state vector is (4) ,and O' dual state is

$$\Phi' = |\Psi_{MS}, |O'_0\rangle\langle O'_0| \gg$$

When at $t > t_2$ measurement by O' finished Q value measured by O' coincides with q_i. To check that Q value coincides for O' and O, O' can perform measurement both Q and Q_O which is described by (11) and gives the same result as in standard QM. It don't contradicts to the previous assumption that for O' before t_2 Q was principally uncertain. The reason is that in between O' interacts with S and it makes Q value definite for him. This measurement demonstrates the subjective character of collapse, which happens only after S interaction with particular observer occurs. It contradicts with standard QM reduction postulate which states that if Q acquired the definite value relative to O then its objectively exists also for O' or any other

observer. Then at $t > t_1$ MS state relative to O' must be the mixture ρ_m of (4). In our formalism at that time MS state vector relative to O' is pure state Ψ_{MS} of (2) which isn't Q eigenstate. To test it experimentally O' can measure $\hat{B}$ on MS which don't commute with Q. If our theory is correct then $\bar{B} \neq 0$ and thus MS state collapse doesn't occurs at $t = t_1$.

It's worth to remind that the state vector has two aspects : dynamical and informational in which Ψ is O maximal information about the studied object S. Our formalism extends this aspect on the case when O measures S and can have more information about S then 'stand-by' O'. In its framework the state collapse directly related with O information acquisition via interaction with S. The same information can be send by O to another O' by some material signal, for example photons bunch. When it measured by O' it result for her into the entangled state Ψ_{MS} collapse to one of its components. Remind that in standard QM with reduction when O measures S he also must send material signal to O' which she must measure to acquier information on Q value. So despite the formal difference between two theories is large the operational difference isn't so significant.

Relativistic analysis of EPR-Bohm pairs measurement also indicates subjective character of state vector and its collapse [26]. It was shown that the state vector can be defined only on space-like hypersurfaces which are noncovariant for different observers. This results correlate with nonequivalence of different observers in our nonrelativistic formalism. Hence we believe EPR-Bohm correlations deserve the detailed study in this dual framework.

4 Discussion

In this paper the measurement models which accounts observer (IGUS) information processing and memorization regarded. Real IGUSes are very complicated systems with many DFs, but the main quantum effects are supposedly the same for large and small systems and can be studied with the simple models. In our approach observers are material local objects which are nonequivalent in a sense that the physical world description can be principally different for each of them [6]. Breuer theorem shows that inclusion of observer as quantum object into measurement model doesn't explains collapse appearance. To obtain it it's neccessary also to modify the quantum states set which makes it nonequivalent for different observers but conserves Schrodinger dynamics for each state.

Our doublet formalism demonstrates that probabilistic represention is generic and unavoidable for QM and without it QM can't acquire any observational realization. Wave-particle dualism was always regarded as characteristic QM feature, but in our formalism it has straightforward description. This dual theory in its present form is the essencially phenomenological one. It don't answers: ' why state collapse exists in QM ?', but describes for which quantum states set it can be done compatible with MS Schrodinger evolution observed by external O'. In our opinion its results evidences that the quantum state by its nature is closer to classical probabilistic distribution then to De Brogile wave, despite it doesn't mean hidden parameters existence. To investigate its physical meaning we propose Information Causality Interpretation which we'll be reported in forcoming paper [27]. Here we

note only that the key problem becomes the existence of the objective reality of any physical values i.e values independent of particular observer. Our formalism hints that no such reality is possible and any value has only subjective reality relative to particular observer.

Note that our formalism is principally different from Hidden Parameters theories where this stochastic parameters influence Quantum state dynamics and so differs from SD. In our model V^O internal parameter j is on the opposite controlled by evolution equation for quantum state, but don't exists objectively before S starts to interact with O.

In dual formalism O percepts only O_j component of complete state vector Ψ_{MS} and it's not clear why other components aren't observed. The tempting explanation can be related to Breuer theorem result which shows that O selfmeasurement is always noncomplete. It's possible to assume that in individual event O can percept only random part O_j of his effective physical state. Thus $V^O(n)$ information loss can be regarded as the consequence stochastic degeneration of Ψ_{MS} and to get more clear picture one should consider statistical state R_O. But it also doesn't give complete MS description as was shown in Breuer papers [8]. In addition remind that S initial state vector describes Q fundamental uncertainty for O i.e. its subjective information on S. When S-O interacted corresponding O internal DFs excited and its internal state correlated with S. It's possible to assume that for O internal states any uncertainty is excluded - i.e. O knows his own state due to continuous interactions inside O and initially uncertain Q percepted as random but certain value. O is the 'last ring' of measurement chain and such singularity can appear.

It's widely accepted now that decoherence effects are very important in measurement dynamics [12, 2]. But the frequent claim that collapse phenomena can be completely explained in its framework was shown to be incorrect at least for simple models [19]. But in our model some kind of decoherence is also present in the form of self-decoherence when S departs from O volume after interaction. In our model additional decoherence effects must appear via account of the interaction of O with its environment E and its effects can be importatnt. Our approach to collapse is close to the decoherence attitude, where also any additional collapse postulate don't used. The main difference is that Decoherence theory claims the collapse is objective phenomena which was proved to be true only in some crude approximation [19]. We suppose that collapse has relational or subjective character and observed only by observer inside decohering system, while for external O this system including E is pure.

As we proposed in the introduction our theory doesn't need any addressing to to human observer consciousness (OC). Rather in this model O is active RF which internal state excited by the interaction with the studied object. The situation with the measurement problem for two quantum observers has much in common with Quantum reference frames introduced by Aharonov [29].

Historically the possible influence of observer on measurement process was discussed first by London and Bauer [28]. They supposed that OC due to 'introspection action' violates in fact Schrodinger equation for MS and results in state reduction. This idea was critisized in detail by Wigner [5]. In distinction in our dual theory OC perception doesn't violate MS Schrodinger evolution from O' point of view. But measurement subjective perception in it also performed by OC and its results partly

independent of dynamics due to its dependence on stochastic V^O. This effect deserves further discussion, but we believe that such probabilistic behavior is general IGUS property not related to OC only.

Dual formalism deserves detailed comparison with formalisms of different MWI variants, due to their analogy - both are the theories without dynamical collapse [1]. In Everett+brain QM interpretations eq. (4) describes so called observer O splitting identified with state collapse [30]. In this theory it's assumed that each O branch describes the different reality and the state collapse is phenomenological property of human consciousness. Obviously this approach has some common points with our models which deserve further analysis. In general all our experimental conclusions are based on human subjective perception. Assuming the computer-brain perception analogy in fact means that human signal perception also defined by $\bar{Q}_O$ values. Despite that this analogy looks quite reasonable we can't give any proof of it. In our model in fact the state collapse have subjective character and occurs initially only for single observer O [6]. Copenahgen interepretation based heavily on the micro/macro world partition. Our theory indicates that if it's sensible to discuss any world partition prompted by QM results it seems to be the division between the subject and the objects. Here subject is observer O which collect information about surrounding world and the objects can include other observer O'.

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